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Editor-in-Chief
PAUL D. FOOTE
Gulf Research Laboratory
327 Craft Avenue, Pittsburgh, Pa.

Assistant Editor-in-Chief
F. K. RICHTMYER
Cornell University,
Ithaca, N.Y.

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THOMAS YOUNG, THE MAN AND PHYSICIAN*

By Horatio B. Williams

The life histories of those who have achieved signal distinction in any field of human endeavor are always matter of compelling interest. But the biographies of the men, whose contributions to the knowledge of science have been so fundamental as to have moulded the thought of a scientific epoch, afford material worthy of the closest study. We are able to perceive in many little incidents influences which have determined the course of subsequent important events; our minds become better prepared to follow the details of those particular developments on which the individual's reputation is principally based.

Thomas Young's fifty-six years were well filled with matter which might hold the attention of those not easily entertained; and the fullness of this life began early, for he could read fluently at the age of two years. So great is the wealth of material that one restrains with difficulty the impulse to dilate upon it at too great length. Although within the limits of time available I cannot even mention many matters which I am sure would entertain, it is possible to inform you as to the sources of information. First there is a Memoir of Thomas Young, published anonymously by a friend who regrets his inability to discuss many aspects of Young's work. This Memoir is dated 1831. In 1832 there was read at a public session of the French Academy of Sciences by its president, Arago, an Eulogy of Thomas Young, for which the data have evidently been largely taken from the Memoir of 1831. A translation of this Eulogy was published in 1872 in the Report of the Smithsonian Institution for the Year 1869. The most complete

* Read at the Thomas Young Memorial Meeting of the Optical Society of America at Ithaca, N. Y., November 24, 1929.

biography of Dr. Young is the "Life of Thomas Young," by George Peacock, Dean of Ely and Lowndean Professor of Astronomy at Cambridge. This was published in London in 1855. It is inscribed, "To Hudson Gurney, Esq., one of the oldest and most valued of the friends of Dr. Young," and in the preface one learns that Mr. Gurney was the author of the anonymous Memoir. The two large quarto volumes of the Natural Philosophy were published in London in 1807 and The Miscellaneous Works of Dr. Young, edited by Dean Peacock and John Leitch, Esq., were published in London in 1855.

Thomas Young was born at Milverton in Somersetshire, England, on June 13, 1773, and died in London on May 10th, 1829. His parents were members of the Society of Friends and he was brought up in the tenets of that faith, a circumstance which exercised a profound influence upon his life. His mother was a niece of Dr. Richard Brocklesby, an eminent London physician, who numbered among his intimate personal friends most of the Londoners of the time who were worth the acquaintance of a man of culture. Dr. Brocklesby was a man of means as well as of education and professional distinction. His interest in his grandnephew was another of the circumstances which had a determining influence on Young's life.

The boy's ability was astonishing. He had read the Bible through twice at the age of four and his memory was remarkable. Dr. Peacock found a note pencilled by Mr. Davis, Dr. Young's maternal grandfather, in a quarto edition of Goldsmith's Deserted Village, to the effect that Thomas Young had repeated this poem to him verbatim, with the exception of a word or two, before he was five years old.

The first seven years of his life were spent largely at the home of Mr. Davis, where under the instruction of his aunt, Mary Davis, and his grandfather, he learned to read. When not quite six years old he began learning the rudiments of Latin grammar. At the age of fourteen he wrote, in Latin, an autobiography of himself from his earliest recollections to that date. This was the source of most of Dr. Peacock's information regarding those years. In this sketch Young mentions that at the age of seven he was sent to a boarding school whose master he describes as severe and morose. "A man whose manners and character were little calculated to gain the confidence and affection of his students." Arago surmises that his experience in this school helped to develop in him the habit of independence in the acquisition of knowledge which was one of his outstanding characteristics. On leaving this school he spent a half year at home. During this time he made the

acquaintance of a neighbor of his father, a man who, though originally a tailor, had become a self educated land surveyor, To this man, a Mr. Kingdon, and his family the lad became much attached as did they to him. He was permitted access to Mr. Kingdon's books and instruments and taught the use of the latter by Mr. Kingdon's daughters and by his nephew. Of the books, A Dictionary of the Arts and Sciences, in three quarto volumes, awakened keen interest. This acquaintance seems to have been the first contact with science in the life of this boy whose early education is so strongly tinged with the ancient classics. At the age of thirteen he had read an impressive list of the works of standard Latin and Greek authors. He attended diligently to composition in the languages he studied, often paraphrasing English poetry into Greek elegiacs.

After a half year at home he attended another and better boarding school, where the usher, a Mr. Josiah Jeffrey, loaned him books on natural philosophy and taught him the use of the lathe and how to make telescopes. About the same period he came to know a saddler named Atkins, who lived at Minehead near his grandfather's home. Atkins was a man of scientific tastes. He had made over a long period of years systematic observations of temperature and barometric pressure in connection with wind direction and velocity and the state of the weather. This work was so well esteemed as to be published by the Royal Society. Mr. Atkins possessed a quadrant which he permitted the boy to use. In the Latin autobiography he describes the pleasure he derived from measuring with this instrument the heights of various eminences in the neighborhood.

He presently became interested in the study of botany and desired to have a microscope with which to examine the fine structure of plants. Having found in the works of Benjamin Martin instructions for making a microscope, he procured a lathe and assembled the materials. During the period of construction his zeal for botany cooled somewhat, having given place to an intense interest in optics and in turning. In reading Martin he found a demonstration in which, as it turned out unnecessarily, there occurred fluxional symbols. He never felt satisfied until a year or two later he read a short introduction to the method of fluxions. His father purchased at an auction a volume of Priestley on Air, the reading of which Young says, "Delighted me greatly and first turned my attention to making chemical experiments."

He learned to read Italian because one of his schoolmates read that language and loaned him books.

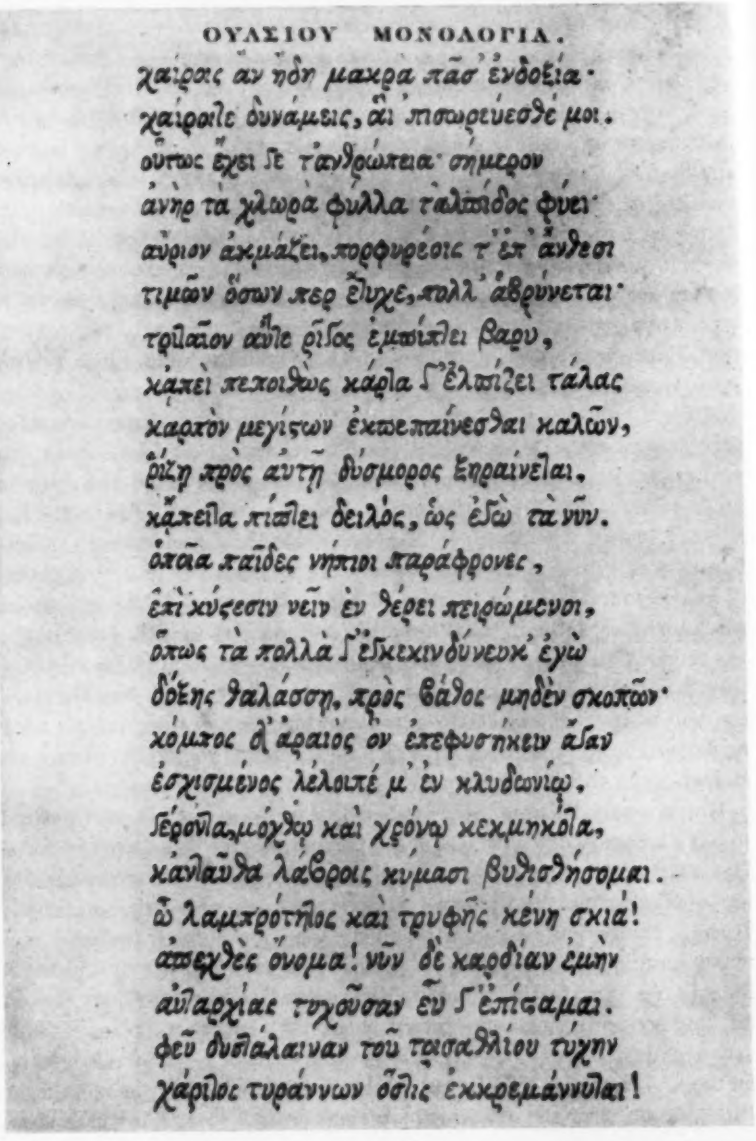
ΟΥΛΣΙΟΥ ΜΟΝΟΛΟΓΙΑ.
χαίροις ἂν ἤδη μακρὰ πᾶσ' ἐνδοξία·
χαίροιτε δυνάμεις, αἳ πισωρεύεσθέ μοι.
οὕτως ἔχει τε τἀνθρώπεια· σήμερον
ἀνὴρ τὰ χλωρὰ φύλλα τἀλλοίδος φύει·
αὔριον ἀκμάζει, πορφυρέοις τ' ἐπ' ἄνθεσι
τιμῶν ὅσων περ εἶυχε, πολλ' ἄβρύνεται·
τριταῖον αὖτε ῥῖζος ἐμπίπλει βαρυ,
κἀπεὶ πεποιθὼς κάρτα σ' ἐλπίζει τάλας
καρπὸν μεγίστων ἐκπεπαίνεσθαι καλῶν,
ῥίζῃ πρὸς αὐτῇ δύσμορος ξηραίνεται.
κἄπειτα πίπτει δειλός, ὡς ἐξὼ τὰ νῦν.
ὀπαῖα παῖδες νήπιοι παράφρονες,
ἐπὶ χύσεσιν νεῖν ἐν δέρει πειρώμενοι,
ὅπως τὰ πολλὰ σ' ἐκκεκινδύνευκ' ἐγὼ
δόξης θαλάσσῃ, πρὸς βάθος μηδὲν σκοπῶν·
κόμπος δ' ἀραιὸς οὐκ ἐπεφυσήκειν ἄσαν
ἐσχισμένος λέλοιπέ μ' ἐν κλυδωνίῳ.
γέροντα, μόχθῳ καὶ χρόνῳ κεκμηκότα,
κἀνταῦθα λάθροις κύμασι βυθισθήσομαι.
ὦ λαμπρότητος καὶ τρυφῆς κενὴ σκιά!
ἀσεχθὲς ὄνομα! νῦν δὲ καρδίαν ἐμὴν
αὐταρκίας τυχοῦσαν εὖ σ' ἐπίσταμαι.
φεῦ δυσπάλαιναν τοῦ τρισαθλίου τύχην
χάριτος τυράννων ὅστις ἐκκρεμάννυται!

FIG. 1. *Facsimile of original written on vellum by Thomas Young, illustrating the beauty of his Greek chirography. The specimen is a translation made by him of Woolsey's soliloquy. Taken from Peacock's Life of Thomas Young.*

When he returned from boarding school he tells us that his time was devoted almost entirely to the study of Hebrew and to the making of telescopes, a combination of interests which seems a bit odd. Within a short time he had read through thirty chapters of the book of Genesis, without points.[1] A gentleman who had heard of his Hebrew studies loaned him Masclef's Hebrew, Chaldee, Syriac and Samaritan grammars and the Lord's Prayer in more than one hundred languages, which latter he says he "examined with extraordinary pleasure." At this time he also read the greater portion of Sir William Jones' Persian grammar. When it is borne in mind that this remarkable boy read to understand and to remember, this account of his activities would be almost unbelievable were it not borne out by his later life.

It is related that while on a visit to his uncle, Dr. Brocklesby, he was asked by one of the Doctor's friends who had heard of his excellent penmanship, to write him a copy. Perhaps Young's very youthful appearance had betrayed the Doctor's friend into adopting a patronizing air; at all events the youngster adminstered a mild Quaker rebuke by handing him a copy written in his best style and in *thirteen different languages*.

When Young was about fourteen years old he became known to a Miss Priscilla Gurney, a friend of his mother's sister. Miss Gurney was a niece of Mr. David Barclay, who was at that time making arrangements for the instruction at home under a tutor of his nephew, Hudson Gurney, and was desirous of having another lad of about the same age as a companion. Miss Gurney recommended Young and this was the beginning of his acquaintance with the boy who later was his first biographer. The tutor first engaged was offered a more permanent position and never came. Young, being a year and a half the older of the two boys, assumed the duties of tutor *pro tempore*. When the tutor arrived he found the classical studies progressing so favorably under Young's direction that he permitted him to continue. Dr. Young regarded the five years he spent with Hudson Gurney as among the best of his life.

In 1791, when eighteen years old, he spent the months of November and December with Dr. Brocklesby in London and was introduced to the most distinguished literary society of the day. Those who met

[1] I am told that Hebrew was originally written without vowel characters, these being supplied by a reader sufficiently familiar with that language. Later certain marks called "points" were introduced to indicate vowel sounds. It was considered a mark of classical scholarship in Young's time to be able to read Hebrew without points.

him were surprised and delighted to find that he could maintain his part of a discussion with ease and dignity, yet quite without affectation.

In the autumn of 1792 he took lodgings in Westminster and entered the Hunterian School of Anatomy in preparation for the study of medicine, a choice of profession probably influenced, perhaps dictated, by his uncle. The year following he became a student at St. Bartholomew's Hospital. In dissecting an ox eye he became interested in the structure of the lens. It had been suggested by Pemberton that the fibers of the lens might be muscular and by their contraction bring about the adjustment for near vision. Young thought that in his dissection he had found evidence for this muscularity. He presented his views in a paper, written in masterly style, which was read at the Royal Society and was regarded as so meritorious that in the year following he was elected to fellowship in that body. The hypothesis was erroneous, but it must be remembered that the facilities for the study of histology at that time were very limited. The paper was given an importance which, perhaps, it hardly deserved, by reason of the fact that so soon as it appeared the famous John Hunter laid claim to priority in the discovery.

The winter of 1794–95 he spent in medical studies at the University of Edinburgh. This period marked his abandonment of various of the external forms of religious observance characteristic of the Quakers. He found it increasingly difficult to maintain desired social contacts and still adhere to the peculiar forms of dress and language used by the Society of Friends. Also he saw no valid reason for abstention from dancing or attendance at the theater. In making these readjustments, however, he never abated anything of strict adherence to principle. His stay in Edinburgh was both pleasant and profitable. His great attainments made him everywhere a welcome guest.

The following year he went to Goettingen to complete his medical studies. Here he combined the acquisition of professional knowledge with the mastery of those accomplishments from which in earlier life he had been debarred. Twice a week he took lessons in dancing and he devoted a like amount of time to lessons in playing on the clavichord and flute. He was passionately fond of equitation and rode four times a week at the Academic Riding School, then one of the most famous in Europe. He became an accomplished horseman.

On the sixteenth of July, 1796, he defended his thesis and with quaint ceremony was married to *Hygeia* and created a Doctor of Physic, Surgery and Man-midwifery. He remained in Germany until Feb-

ruary, 1797, travelling extensively and visiting the important universities.

From the time of Queen Elizabeth there had been in force in England certain laws relating to admission to the practice of medicine, which, while they may have been admirable when enacted, had come to be recognized as not altogether equitable under conditions then obtaining. There had been talk of a change and it had seemed so certain it would be made that the plan of Young's education at Edinburgh and Goettingen and been based on this supposition. On returning to London he found that the expected change had not been made and that he must spend two years more at either Oxford or Cambridge in order to comply with the law. He accordingly took up residence at Cambridge as a Fellow Commoner of Emmanuel College. Here he remained two years, but was not admitted to the baccalaureate degree in medicine until 1803, nor to the doctorate until five years later when he was thirty-five years old, at which time he was admitted to fellowship in the Royal College of Physicians.

At Cambridge he was under the disadvantage of undergraduate status, though far more advanced than the average undergraduate. He did not enjoy the restrictions thus placed upon him, but it was without doubt a useful period. During his boyhood he had little contact with children of his own age. He was brought up in a religious sect which took a serious view of things and the outlook on life which he adopted was naturally a serious one. At Cambridge he learned that in spite of all the accomplishments of his boyhood and those he had acquired on the Continent, there was still something lacking. On one occasion he remarked, "When I was a boy, I thought myself a man; now that I am a man, I find myself a boy."

An idea of his personality as it impressed his contemporaries at Cambridge may be gleaned from the remarks of one of them. In appraising the value of these opinions it should be remembered that they are those of a man not an intimate friend of Young and not capable of appreciating fully his intellectual quality.

There follow some selected paragraphs from a letter this gentleman wrote:

"He had a high character for classical learning before he came to Cambridge; but I believe he did not pursue his classical studies in the latter part of his life—he seldom spoke of them; but I remember his meeting Dr. Parr in the College Combination room, and when the Doctor had made, as was not unusual with him, some dogmatical observation on a point of scholarship, Young said firmly: 'Bentley, sir, was of a different opinion'; immediately quoting his authority, and showing his intimate knowledge of the subject. Parr said nothing, but when

Dr. Young retired, asked who he was, and though he did not seem to have heard his name before, he said, 'A smart young man that'. "

"He had a great talent for Greek verse; and on one occasion I remember a young lady had written on the walls of a summer house the following lines:

'Where are those hours on airy pinions borne,
That brought to every guiltless wish success?
When pleasure gladdened each succeeding morn,
And every ev'ning closed with dreams of peace?'

On the next morning appeared a translation in Greek Elegiacs, written under them in Young's beautiful characters . . . . . "He never obtruded his learning in conversation, but if appealed to on the most difficult subject, he answered in a quick flippant, decisive way, as if he was speaking of the most easy; and in this mode of talking he differed from all the clever men that I ever saw. His reply never seemed to cost him an effort and he did not appear to think there was any credit in being able to make it. He did not assert any superiority, or seem to suppose that he possessed it; but he spoke as if he took it for granted that we all understood the matter as well as he did. He never spoke in praise of any of the writers of the day, even in his own peculiar department, and could not be persuaded to discuss their merits. He was never personal; he would speak of knowledge itself, of what was known or what might be known, but never of himself or any other as having discovered anything, or as likely to do so."

Of the truth of this last remark his printed works bear internal evidence. In reading the two volumes of his Natural Philosophy it is extremely difficult to determine in some cases where his statements are the results of his own observations.

"His language was correct, his utterance rapid, and his sentences, though without any affectation, never left unfinished. But his words were not those in familiar use, and the arrangement of his ideas seldom the same as those [of the people][2] he conversed with. He was, therefore, worse calculated than any man I ever knew for the communication of knowledge."

"In his manners he had something of the stiffness of the Quaker remaining; and though he never said or did a rude thing, he never made use of any of the forms of politeness. Not that he avoided them through affectation; his behaviour was natural without timidity, and easy without boldness. He rarely associated with the young men of the college, who called him, with a mixture of derision and respect, 'Phaenomenon Young,' but he lived on familiar terms with the Fellows in the Common-room. He had few friends of his own age or pursuits in the University; and not having been introduced to many of those who were distinguished either by their situation or talent, he did not seek their society, nor did they seek him; they did not like to admit the superiority of any one in *statu pupillari*, and he would not converse with anyone but as an equal.

It is difficult to say how he employed himself; he read little, and though he had access to the college and university libraries, he was seldom seen in them. There were no books piled on his floor, no papers scattered on his table, and his room had all the appearance of belonging to an idle man. I once found him blowing smoke through long tubes, and afterwards saw a representation of the effect in the Transactions of the Royal Society to illustrate one of his papers upon sound, but he was not in the habit of making experiments. He walked little and rode less, but having learnt to ride the great horse abroad, he used to pace round Parker's Piece on a hackney: he once made an attempt to follow the hounds, but a severe fall prevented any future exhibitions."

[2] Bracketed words inserted by the writer.

Perhaps his course of equitation at Goettingen had not included fencing, or more likely he was given a miserable mount for his first and only appearance in the hunting field.

"He seldom gave an opinion, and never volunteered one. He never laid down the law like other learned Doctors, or uttered apothegms, or sayings to be remembered. Indeed, like most mathematicians, (though we hear of abstract mathematics), he never seemed to think abstractedly. A philosophical fact, a difficult calculation, an ingenious instrument, or a new invention would engage his attention; but he never spoke of morals, or metaphysics, or of religion. Of the last I never heard him say a word, nothing in favor of any sect, or in opposition to any doctrine; at the same time, no sceptical doubt, no idle scoff ever escaped him."

Such a man did Thomas Young appear to his associates at Cambridge at the age of twenty-five.

In December 1797, his uncle died suddenly. He left to Dr. Young his town house in Norfolk Street, Park Lane, with the furniture, library, prints and a choice collection of paintings, chiefly selected by his friend, Sir Joshua Reynolds; and about ten thousand pounds. Dr. Young continued to reside in Cambridge during such portions of each term as the statutes required, keeping apartments in his uncle's house for use when in London. The records of Young's life at Cambridge are meager, but it appears that during the latter part of his residence there he made a considerable circle of acquaintances among people of note.

In the year 1800, having completed the last term of his required residence at Cambridge, he established himself in practice in London. The following year he accepted the post of professor of natural philosophy at the Royal Institution. In 1802 he was appointed Foreign Secretary of the Royal Society. He lectured at the Royal Institution for two years and then resigned the position for a reason which in our day seems peculiar. It was feared by his friends that the public might suspect his medical skill not to be all that it might be if it were known that he continued to devote a considerable part of his time to scientific pursuits not immediately connected with the practice of medicine. On quitting this position, he proceeded to write out his lectures for publication. The work was published in 1807 in two large quarto volumes, the second containing besides several scientific papers, a treatise on mathematical physics and a catalog of published works which he had consulted. On page 190 of the first volume is a description of a chronometer for the measurement of short intervals of time by the use of a drum which revolves uniformly in a spiral path, its rate being controlled by a centrifugal governor. At the end of the volume is a cut of this

instrument, (Fig. 2), which seems to have been invented by Dr. Young himself and to have been the first application of a revolving drum for this purpose.

As an example of the clearness of Dr. Young's thinking and of the cogency of his reasoning in fields other than optical I would recommend

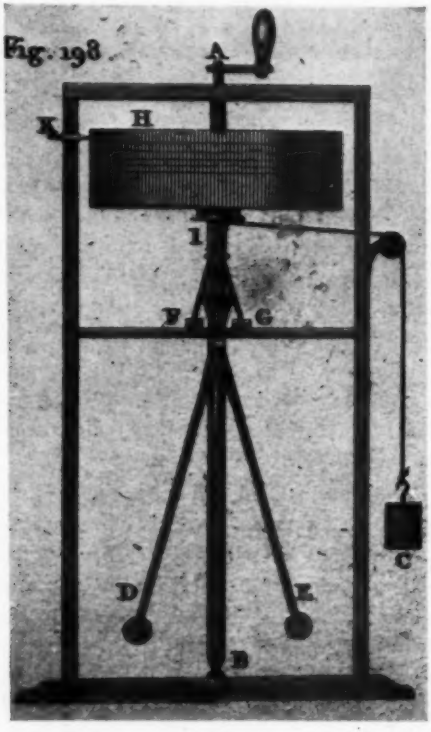

FIG. 2. *Young's drum chronograph, from a plate in the Natural Philosophy.*

the reading of Lecture 52, pages 646–57 of Vol. 1 of the Lectures. I shall quote a single sentence, which you will bear in mind was spoken one hundred and thirty years ago: "If heat is not a substance, it must be a quality; and this quality can only be motion." In Lecture 13 On Passive Strength and Friction, is a passage which shows the simplicity and directness of his reasoning. "When a beam is supported at both ends, its stiffness is twice as great as that of a beam of half the length, firmly fixed at one end . . . . . For if the whole beam were

inverted and supported by a fulcrum in the middle, each half would resemble a separate beam fixed at one end, and the fulcrum would bear the sum of two equal weights placed at the extremities, disregarding that of the beam; and consequently the same flexure will be produced by placing a double weight on the middle of the beam in an inverted position." In this same lecture on page 137, is to be found the definition of the modulus of elasticity, Young's Modulus, which is the first item in the study of physics which the student is likely to associate with the name of Dr. Young. It is characteristic of his writing that no mention is made of any claim to originality in connection with this concept. A more terse statement of it is given in Volume 2, page 46 in the mathematical section as follows: "The modulus of elasticity of any substance is a column of the same substance, capable of producing a pressure upon its base which is to the weight causing a certain degree of compression, as the length of the substance is to the diminution of its length."

We have already referred to his early paper before the Royal Society on the nature of accommodation in the eye. In 1800 he read a second paper, published in Volume 2 of the Lectures. This paper is remarkable for the description of physiological experiments planned with consummate skill. He located the blind spot in the field of vision so that he could accurately infer the position of the optic nerve head in the living eye, made measurements of the refractive index of the crystalline lens and determined that the curvature of the cornea remains unchanged in accommodation. He also showed that accommodation cannot be referred to changes in the antero-posterior diameter of the eyeball, the methods he used being such that they would have detected with certainty changes far less than he correctly calculated would be requisite to produce the observed effect on refraction. He leans, as in the original paper, to the view that the lens alters its shape owing to changes of the same kind as occur in contracting muscle. He thought he determined that no connection exists between the ciliary processes and the lens capsule. In this he was mistaken. He remarks on the fact that the lens can be deformed by pressure and will recover its shape when the pressure is released. Considering the difficulty of histological studies and the means at his disposal, we wonder less at his mistakes than at what he accomplished. In his masterly treatment of this difficult subject he lacked but little of completing the discovery which waited half a century for the genius of his illustrious admirer, Helmholtz.

Not the least of Dr. Young's achievements were his contributions to the deciphering of the Egyptian hieroglyphics, or sacred characters. These appear to have been originally a pictorial sign language similar to Chinese. There is in the British Museum a piece of basalt originally discovered by the French about the beginning of the nineteenth century and known as the Rosetta Stone. On this is engraved a proclamation in three languages, of which one is Greek. From this it was learned that the other two inscriptions conveyed the same proclamation in hieroglyphics and in the enchorial characters which were the common written language of Egypt at a later date. There were certain groups of hieroglyphics enclosed in borders, technically known as "rings" and two of these groups which were identical seemed to correspond to the name Ptolemy in the Greek version, while another ring contained these same characters preceded by another group. Young had the happy thought that the expression of a proper name in pictorial language would be difficult unless in some manner the signs might be given phonetic value. His original surmise was that enclosure in a ring was an indication of phoneticization. It was later shown that the ring was reserved for names of royalty, but the clue was important. It eventually led to the knowledge that the giving of phonetic values to the hieroglyphics had come into very extensive use. Young studied a great number of papyri taken from mummies. In some of these the characters were the typical bold hieroglyphics found on the monuments, but there were variants which eventually led to the conclusion that the enchorial characters were derived from the hieroglyphics and bore to them something of the relation of script to print. The honor and the labor of bringing this work to completion was shared by a number of men, but Dr. Young's work is recognized as having laid the foundation. He also contributed to the study of manuscripts obtained from the ruins of Herculaneum and on numerous occasions applied his linguistic knowledge to the restoration of partially obliterated inscriptions.

It is of interest to know that Mrs. Young was a lady of no common intellectual attainments. In his Eulogy, Arago, after noting that the first cordial reception of the undulatory theory of light was in France, goes on the remark: "I will add that at an epoch considerably before the doctrine of interferences had made converts either in England or on the Continent, Young found within his own family circle one who comprehended it and whose assent to it might well have consoled him for the neglect of the public. The distinguished person[3] whom I here

[3] Mrs. Young was at this time still living.

point out to the notice of the physicists of Europe will excuse me if I complete the indiscretion by stating the circumstances. In the year 1816 I made a tour in England with my scientific friend, M. Gay-Lussac. Fresnel had just then entered on his scientific career in the most brilliant manner by the publication of his memoir on diffraction. This work, which in our opinion contained a capital experiment irreconcilable with the Newtonian theory of light, became naturally the first subject of our discussion with Dr. Young. We were astonished at the numerous qualifications which he put upon our praises of it until at length he stated to us that the very experiment which we so much commended had been published so long ago as 1807, in his Treatise on Natural Philosophy. This assertion did not seem to us well founded. It caused a long and minute discussion. Mrs. Young was present without appearing to take any part in the conversation, but we imagined the weak fear of being designated by the ridiculous sobriquet of *bas-bleu* rendered the ladies of England very reserved in the presence of foreigners, and our want of discernment did not strike us until the moment when Mrs. Young quickly quitted her place; we then began to attempt excuses to her husband, until we saw her reenter the room carrying under the arm a large quarto volume. This was the first volume of the Natural Philosophy. She placed it on the table and without saying a word opened it at page 787 and pointed with her finger to a diagram in which the curvilinear route of the diffracted bands, on which the discussion turned, was theoretically established."

On numerous occasions Dr. Young was called upon by the State to serve upon scientific commissions for the settlement of important questions. In 1810 he served on a commission appointed by the Admiralty to look into a proposed modification in the framing of ships. In 1816 he served on the commission to determine the length of the second's pendulum and pointed out an important error in the correction for reduction to sea level. In 1814 he served on a committee of the Royal Society appointed to investigate the danger which might ensue from the general introduction of illuminating gas in London, especially from the construction of large gasometers in crowded neighborhoods.

In November 1818 he was appointed Superintendent of the Nautical Almanac and Secretary of the Board of Longitude. This last appointment was destined to become a thorn in the flesh and is one phase of Dr. Young's public life in which his judgment has seemed open to criticism.

Among the many subjects treated by this versatile Doctor of Medicine was a mathematical theory of the tides, a work which he was accustomed to regard as the most successful of all his excursions into mathematical physics. On account of the inherent difficulty of the work, it was little read and has been less noticed than some of his other contributions, though at the time it was undoubtedly the best work on the subject and remained so until the publication of Airy's treatise.

At the request of one of the large Life Assurance Societies, he undertook actuarial studies and went extensively into this subject. He published some hydrodynamical studies which were followed by a treatise on the dynamics of the blood circulation. This investigation involved the use of a value for the average diameter of the red blood corpuscles which he obtained by the use of an instrument of his own invention in which the corpuscles cause diffraction of light. He also used this instrument for measuring the average diameters of woolen fibers, from which he gave it the name, eriometer.[4] Dr. W. F. Emmons, of Montreal, has recently revived the use of this instrument in a convenient form for measurement of the diameters of blood corpuscles.[5]

Dr. Young studied the always interesting question of the mathematical treatment of the results of observation.[6] He discussed the figure of the earth as modified by the elastic properties of its components and pressure and dealt with the phenomenon now known as isostasy. In connection with his position on the Board of Longitude he interested himself in terrestrial magnetism and wrote a memoir on the effects on ships' compasses of magnetic masses on the ship, giving tables for correction of the residual magnetic effects and for the modification of these effects by variation of the dip.[7] It was Young who first introduced into physics the concept of energy.

Had Thomas Young never written a word on the theory of Color vision or on the diffraction of light, the position of his star in the firmament of science would be secure. He has been called the best educated physician of his time and so he was, but he was much more than that.

[4] Remarks on the measurement of minute particles, especially those of blood and of pus. The Miscellaneous Works of Thomas Young, pp. 342–348, London, 1855.

[5] W. F. Emmons, The Clinical Eriometer, Quarterly Journal of Medicine, *21*, No. 81, pp. 83–90 and Plate, October 1927.

[6] Remarks on the probabilities of error in physical observations, Miscellaneous Works, *2*, pp. 8–19.

[7] Computations for clearing the compass of the regular effect of a ship's permanent attraction. Miscellaneous Works, *2*, pp. 102–110.

The quotation from Helmholtz,[8] which the committee, somewhat unkindly, forestalled me from using by printing it on the program, is a tribute of whose sincerity there can be no doubt, since its writer was

FIG. 3. *Thomas Young, painted by Lawrence.*

[8] "Er war einer der scharfsinnigsten Maenner, die je gelebt haben, hatte aber das Unglück, seinen Zeitgenossen an Scharfsinn zu weit überlegen zu sein. Sie staunten ihn an, aber konnten dem kühnen Fluge seiner Combinationen nicht überall folgen, und so blieb eine Fülle seiner wichtigsten Gedanken in den grossen Folianten der Königlichen Gesellschaft von London vergraben und vergessen, bis eine spätere Generation in Langsamem Fortschritte seine Entdeckungen wieder entdeckte, und sich von der Richtigkeit und Beweiskraft seiner Schlüsse überzeugte."

Hermann von Helmholtz, Vortrage und Reden, vierte Auflage, Braunschweig, 1896.

He was one of the most keenly intellectual men that has ever lived, but he had the misfortune that he too far exceeded his contemporaries in sagacity. They wondered at him, but were unable to follow the brilliant flights of his combinations and so there remained a large measure of his most important thoughts buried and forgotten in the great folios of the Royal Society of London, until a later generation in gradual progress re-discovered his discoveries and satisfied itself of the correctness and convincing power of his conclusions.

not given to the pronouncement of unearned eulogies. Also it is the expression of one who was probably better able to appreciate Young's many-sided attainments than any other man.

One can hardly repress a slight feeling of regret that the supposed exigencies of medical practice should have been allowed to limit Dr. Young's freedom of publication, for it is doubtful whether he permitted them greatly to limit his activity. Similar regrets have been expressed regarding Newton's connection with the Mint, and there are not a few parallels between the lives of these two great Englishmen. It seems doubtful, however, whether their total productivity was actually limited by the circumstances mentioned. Both did, or at least began, their greatest works while still young men and this seems to be the usual history of productive work.

More than a hundred years have elapsed since Thomas Young last saw the light which challenged his intellect to its boldest flight, but the art of the painter, Lawrence, has preserved this talisman by whose aid we may pass swiftly down the long avenue of time and feel the charm of his presence. There is something sweetly fascinating about the pictured face of this Quaker lad who was equally at ease whether in the drawing rooms of the brilliant London society which idolized him, among the sick in the wards of St. George's Hospital, or with his intellectual peers in the halls of the Royal Society. From this picture there breathes an influence as soothing as the soft intonation of a benediction.

Athlete, musician, connoisseur of art, classical and oriental scholar, mathematician, actuary, physiologist, physician, renowned physicist; he led a full and happy life. Facing the end with magnificent courage and tranquillity, he appraised the activities of that life and left us the heartening message that he found in it nothing to regret.

DEPARTMENT OF PHYSIOLOGY,
COLUMBIA UNIVERSITY, NEW YORK.

FACTORS INFLUENCING THE SPEED OF INTENSIFYING SCREENS

By Frank E. Swindells

ABSTRACT

The speed of intensifying screens was measured at three arbitrary densities by a sensitometric method. The screen factor was found to increase with shortened development time; to increase with increase of tube potential; to be independent of the tube current from 2 to 35 ma; to be independent of the target film distance from 0.5 to 2.5 meters; to increase as more filtering medium was interposed between the tube and screens; and to vary considerably with the photographic emulsion used. The increase with increasing potential is explained as the effect of the varying energy losses of x-rays of different wave lengths when passing through the front screen, and also by the different relative abilities of x-rays of different wave lengths to excite fluorescence, and to expose silver bromide. The variation of the speed factors with different emulsions is due to different relative sensitivity of the screens to x-rays and to the fluorescent light from the screens.

Intensifying screens are almost universally used in practical radiography. The screen is composed of a layer of fluorescent calcium tungstate, attached in some manner to a more or less flexible support, which is thin and permeable to x-rays. The photographic film, which has emulsion on both sides of the base, is placed between the active layers of two intensifying screens. The whole is placed in a light-tight container known as a cassette, one side of which is practically transparent to x-rays. When the exposure is made, the x-rays after passing through the transparent side of the cassette cause the calcium tungstate to fluoresce, and this fluorescent light adds its effect to that of the x-rays on the photographic film, thereby increasing the efficiency of the photographic process and permitting a considerable reduction in the exposure. The intensification factor of a pair of intensifying screens is defined as the ratio of the two exposures, one made with x-rays alone, and the other made with the aid of screens, necessary to produce equal blackness on the film.

In an earlier investigation[1] the intensification factor was determined by a sensitometric method,—essentially that followed by Wilsey.[2] Curves were obtained by plotting the photographic density against the logarithm of the exposure necessary to produce that density. Two curves were obtained in this way: one representing the action of x-rays

[1] F. E. Swindells, American Journal of Roentgenology and Radium Therapy, *17*, p. 115; 1927.

[2] R. B. Wilsey, Radiology, *2*, p. 311; 1924.

alone on the photographic emulsion, and the other the combined action of x-rays and double intensifying screens. By comparing the two exposures required to produce a given density as determined from these curves the efficiency or intensification factor of the screens was calculated. It was found that the two sensitometric curves did not have the same shape, and as a result the intensification factor varied with the density, being a minimum at the lowest density and increasing rapidly to the region of medium densities, above which it usually decreased slightly.

The present investigation is an application of the above described method to determine what effect, if any, the usual variables of radiographic exposure have on the intensification factor. The variables studied were development time, tube potential, tube current, target-film distance, and filtration corresponding to the material being radiographed. A comparison was also made of the intensification factors obtained with several lots of x-ray films.

Because of the variation of the intensification factor with density, no single value could be obtained which would represent the intensifying action throughout the usual range of densities on a radiograph. A method might be used similar to that developed by Nietz,[3] from that of Hurter and Driffield,[4] for the comparison of speeds of photographic emulsions. This method is open to serious objection for this application, however, because it does not take into consideration exposures made in the region of the toe, or lower portion of the sensitometric curve. With x-ray photographic emulsions this region has considerable extent, especially when the exposures are made by x-rays alone.[1,5,6,7] The most useful portions of a radiograph used for diagnosis are those having light or medium density, corresponding to the toe of the curve. The use of an average intensification factor would be open to objection for the same reason. It was therefore decided to use three values in expressing the intensification, one for low density (0.4), one for medium density (1.2) and one for high density (2.0).

Apparatus and Technique. The exposures were made on ordinary x-ray films with emulsion on both sides. All films used were from the same emulsion, as indicated by the maker's number. One half of the

[3] A. H. Nietz, "Theory of Development," Van Nostrand, pp. 35–38; 1922.
[4] F. Hurter and V. C. Driffield, Journal of the Society of Chemical Industry, *9*, p. 76; 1890.
[5] R. B. Wilsey and H. A. Pritchard, J.O.S.A. & R.S.I., *12*, p. 661; 1926.
[6] H. Franke, Fortschritte auf d. Geb. d. Rontgenstr., *27*, p. 524; 1918.
[7] J. Egert, "Einfuhrung in die Rontgen photographic," pp. 27–30; 1928.

film was placed between two pieces of intensifying screen and the whole placed in a cassette with a thin bakelite front. The same pair of screens was used throughout the work. The various exposure times were controlled by means of a specially constructed sensitometer, sketches of which are shown in Figs. 1 and 2. The shutter (*A*) is constructed of a piece of brass 45 cm by 195 cm and 3.2 mm thick. The

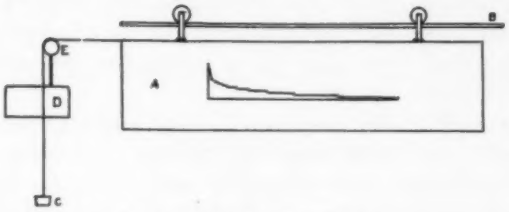

FIG. 1. *Front view of sensitometer.*

shutter has 19 adjacent openings 1 cm wide and varying in length from 1 mm to 1000 mm so that each opening is 1.47 times the length of the next smaller opening. The shutter is backed by a piece of lead 1.9 mm thick with an opening about 5 mm larger than that of the brass plate. The shutter is suspended from the monorail track (*B*) by

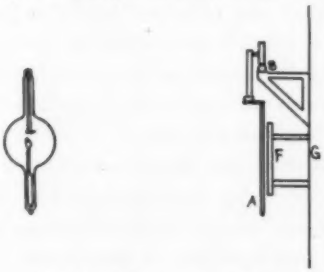

FIG. 2. *Side view of sensitometer.*

two pulleys. The track is attached to the wall by three brackets as shown in Fig. 2. While the exposure is being made the shutter is drawn along the track by the weight (*C*). The track is inclined slightly so that the force of gravity serves to keep the tapes taut and prevent lost motion in the governor which controls the velocity of the shutter. This governor is contained in the gear box (*D*), which also contains a set of interchangable gears, which permit the shutter to be operated at any one of three speeds: 1.25, 12.5 and 125 mm per second. The gear box is connected to the pulley (*E*) by a shaft and bevel gears. A

ratchet is provided for resetting the shutter without operating the gears and governors. The shutter and weight are connected to the wooden pulley (*E*) with two pieces of flexible steel tape, one end of each being firmly attached to the pulley. As one tape unwinds the other winds up. In this way any possibility of slipping and consequent failure of the governor to operate is avoided.

The cassette is supported in a brass frame (*F*) as close to the shutter as possible and about midway in its path. Directly behind the cassette and shutter a large lead panel (*G*) is fastened to the wall to prevent secondary radiation.

The x-ray high tension generator is a mechanically rectified Snook machine, with auto-transformer control and pre-reading voltmeter, calibrated by a sphere gap. A stablizer serves to control the tube current. The Coolidge broad focus universal tube used in all of the experiments is supported on a movable carriage in front of the shutter so that the target-film distance can be varied from 0.5 to 2.5 meters. An aluminum filter 2 mm thick is supported in front of the opening in the heavy lead glass tube shield.

When an exposure is to be made the loaded cassette is placed in its holder behind the shutter. The shutter is pulled down to the low end of the track and the gears and governor adjusted for the desired speed. The x-ray machine is started and adjusted, and the shutter released by an assistant. As the sensitometer openings traverse the film at constant velocity, a series of exposures is made on the film, the time of each being proportional to the length of the corresponding shutter opening. On the portion of the film covered by the intensifying screens the exposures were due to the combined action of the x-rays and the fluorescent light from the screens, and on the remainder the exposure is due to the action of x-rays alone. Thus on one film it is possible to compare the exposures with and without screens, and thereby ascertain the efficiency of the latter. By having both sets of exposures on the same film errors due to small variations in exposure and development are avoided.

The development is carried out in freshly prepared elon–hydroquinone developer containing potassium bromide, and of the usual strength used in radiographic tank development. All developments are made at 18.4°C. (65°F) and for five minutes except where the variation of development time is to be studied. After fixing, washing, and drying the film the photographic densities are measured on a Martens-Maximovitch polarization densitometer. The results are then

plotted against the common logarithm of the exposure time in the usual manner. Two curves are thus obtained for each film, one representing the action of x-rays alone and the other the combined action of x-rays and double intensifying screens.

Effect of Development Time. In Fig. 3 the above described sensitometric curves are shown for three different development times, at 60 kvp, and 10 ma and 0.5 m distance. The greater extent of the curved portion or toe of the x-ray curves will be perceived immediately.

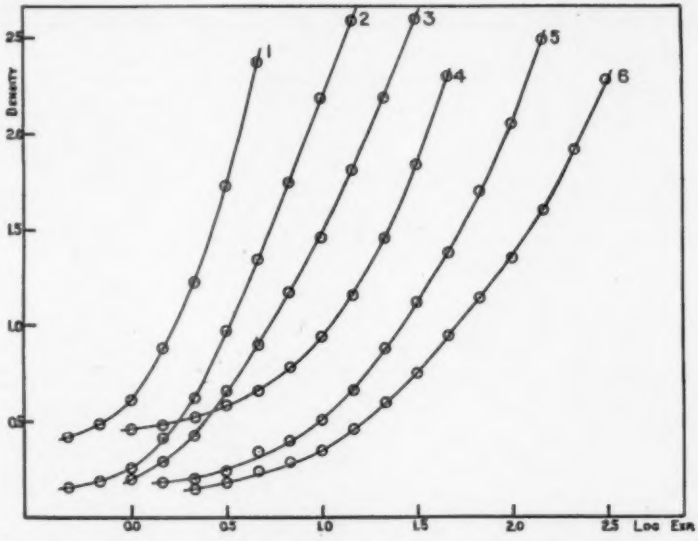

FIG. 3. *Sensitometric curves showing effect of development time. 60 kv, 10 ma, 0.5 m. dist. 1, screens 15 min. dev.; 2, screens 5 min. dev.; 3, screens 3 min. dev.; 4, x-rays 15 min. dev.; 5, x-rays 5 min. dev.; 6, x-rays 3 min. dev.*

The increase in slope of the curves with increased development is also quite apparent. From these curves the exposure ratios or intensification factors are calculated for the three densities 0.4, 1.2 and 2.0, and the results shown in Fig. 4. Fig. 4 contains points for other development times which were omitted from Fig. 3 in order to avoid confusion. It is evident that as the development time is increased the intensification factor at a given density decreases.

The difference in shape of the two sensitometric curves is found to persist throughout the development, and largely explains the variation of the intensification factors at constant density. This difference in

shape is probably due to the fundamental difference in the action of x-rays and light on a photographic emulsion, it being evident that in most cases the bulk of the screen exposure is due to light. In fact it has been shown,[7,8] that the developable silver halide grains in an emulsion sensitized by exposure to x-rays are uniformly distributed throughout the emulsion layer, whereas exposure by screens causes sensitization primarily at the surface of the emulsion.

The important result for the radiographer to consider is that over-development has but little influence on the intensification factor, but that considerable under-development may cause a marked increase in the factor.

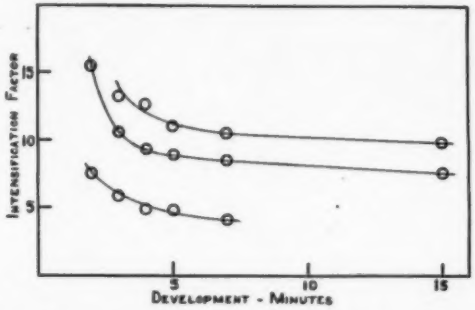

FIG. 4. *Variation of intensification factor with development time. 60 kv, 10 ma, 0.5 m dist. 1, great density (2.0); 2, medium density (1.2); 3, light density (0.4).*

Variation of the Tube Potential. It has been previously determined,[9,2] that with increasing tube potential there is a corresponding increase in the intensification factor, and the following measurements confirm this observation. A series of exposures were made in which the distance and tube current were kept constant at 0.5 m and 10 ma, respectively, and the tube potential varied from 30 to 120 kvp, as measured by a sphere gap. In this and all succeeding experiments the development time was five minutes. The results are shown in Fig. 5. It will be seen that increasing the kvp increases the intensification factor. In this case we have two effects operating which might cause the intensification factor to vary: first, the unequal relative abilities of x-rays of different wave lengths to excite the fluorescence of the screens, and render the silver bromide developable; and second, the varying absorption of the front

[8] F. E. Swindells, Radiology, *11*, p. 424; 1928.
[9] J. G. Farrer, Brit. J. Rad., *32*, p. 368; 1927.

screen for x-rays of different wave lengths. It has been reported[10] that varying the hardness of the exciting x-rays changes the spectral distribution of the fluorescent light. The effect observed was small, however, and probably has but slight influence on the variation of the intensification factor.

De Broglie[11] found that the fluorescence of calcium tungstate gradually increased with increasing hardness of the rays. Since when the potential is raised the resulting x-ray beam contains a greater proportion of hard rays, we should naturally expect the intensification factor to increase. He also found that the ability of x-rays to render silver bromide developable was greatly enhanced when the rays lay in the

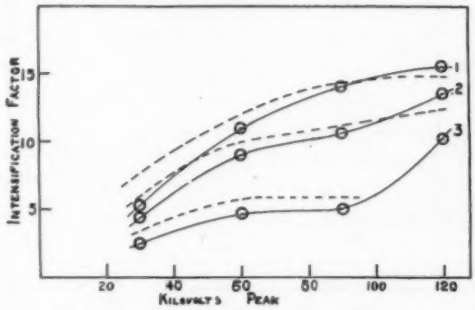

FIG. 5. *Variation of intensification factor with tube potential, 10 ma, 0.5 m dist. 1, great density (2.0); 2, medium density (1.2); 3, light density (0.4). Dotted lines represent special combination with thin front screen.*

spectral region of the selective absorption bands of silver and bromine. As the potential of the tube is raised, a greater proportion of the rays have shorter wave lengths than 0.48A, the *K* absorption limit for silver, and the beam becomes relatively more efficient in exciting fluorescence than in exposing silver bromide directly.

Since with screen exposures the x-ray energy must penetrate the front screen before it becomes effective, it should be expected that at low voltages there would be a considerable amount of energy which is unable to penetrate deeply enough into the front screen to produce fluorescence. The dotted lines shown in Fig. 5 represent a special combination of a front screen containing an unusually thin layer of fluorescent material and a regular back screen. It will be seen that at

[10] M. B. Hodgson, Physical Rev., (2), *12*, p. 431; 1918.
[11] M. De Broglie, Comp. Rendu., *170*, p. 1053; 1920.

the lower voltages the special combination is more effective than the regular combination, a confirmation of the results of Stumpf.[12]

It appears that the combined result of the above described effects operates in such a manner that as the kvp is raised the intensification factor increases.

Variation of Tube Current. The kvp and distance were kept constant, and the tube current varied from 2 to 35 ma. The intensification factor is found to decrease slightly as the tube current increases, but the decrease is not of sufficient magnitude to have much practical importance. It may be due to a variation in the form of the rectified wave and resulting variation in the distribution of the energy in the x-ray

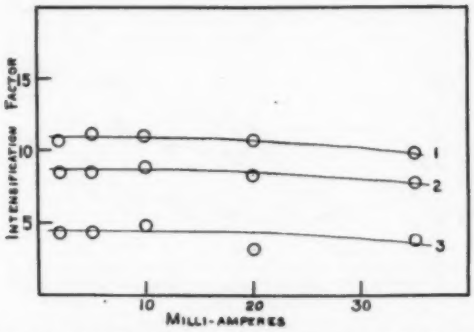

FIG. 6. *Variation of intensification factor with tube current, 60 kv, 0.5 m dist. 1, great density (2.0); 2, medium density (1.2); 3, light density (0.4).*

spectrum when the current is varied although the kvp remains constant.[9] It is also of interest that in these experiments there is no evidence of the existence of a saturation value of the fluorescent light, beyond which increase in stimulus could cause no increase in the output of fluorescent light. If such a saturation value existed within the range of these experiments, a decided falling off of the intensification factor with increasing tube current would be expected.

Variation of Target-Film Distance. Two effects might be expected to operate to alter the intensification factor as the distance is changed. As the tube is brought closer to the screens the intensity of the beam falling on the screens increases approximately as the inverse square of the distance. Thus if a saturation value of the fluorescence existed, the intensification factor would decrease when the tube is brought very

[12] P. Stumpf, Fortschritte auf d Geb. d Rontgenstr., *37*, p. 185; 1928.

close to the screens. This point could not be tested with the sensitometer, as it was not practical to bring the tube closer than 0.5 meter from the cassette. Second, the beam might change in quality due to absorption by the air with a resulting effect on the intensification factor. The results shown in Fig. 7, show that the intensification factor is

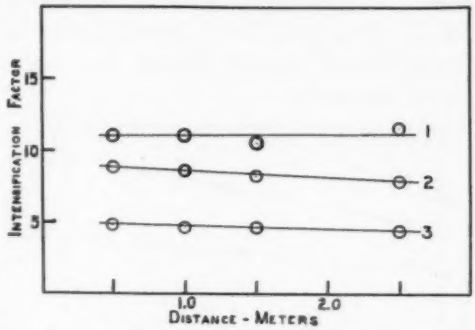

FIG. 7. *Variation of intensification factor with target film distance. 60 kv 10 ma. 1, great density (2.0); 2, medium density (1.2); 2, light density (0.4).*

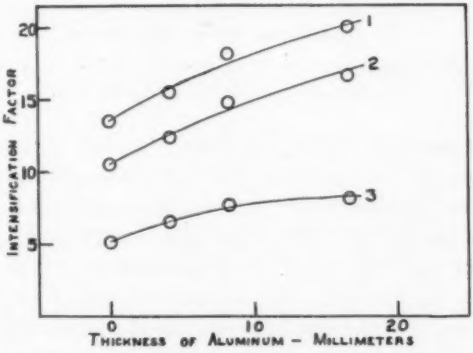

FIG. 8. *Effect of absorption by aluminum, 90 kv 10 ma, 0.5 m dist. 1, great density (2.0); 2, medium density (1.2); 3, light density (0.4).*

practically independent of the distance in the range from 0.5 to 2.5 meters, so that atmospheric absorption has little effect on the factor.

Effect of Introducing an Absorbing Medium. Wilsey[2] in his measurements used a filter of 1 cm of aluminum as being equivalent to the absorption of an average radiograph, and used an empirical factor as a correction for secondary radiation. In these experiments two types of absorbing media were used, the first, aluminum, producing only small

amounts of secondary radiation, and the second water, producing larger amounts of secondary x-rays. The water was contained in thin walled bakelite cells about 35 by 45 cm cross section, supported as close as possible to the sensitometer shutter. With both types of filtration it will be seen from the curves that as the thickness of the filtering medium increases, the intensification factor increases. Thus the increase in hardness of the original beam due to the removal of the softer components by absorption greatly overbalances the effect of the secondary radiation produced.

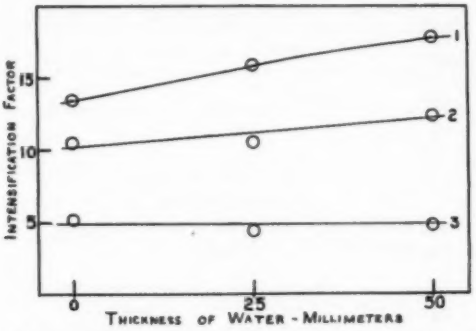

FIG. 9. *Effect of absorption by water. 90 kv, 10 ma, 0.5 m dist. 1, great density (2.0); 2, medium density (1.2); 3, light density (0.4).*

The Intensification Factors of Several X-Ray Emulsions. It has previously been pointed out that[9] the same intensifying screens might have different intensification factors when different photographic emulsions are used. Only when two emulsions have the same relative speeds to light and x-rays will the intensification factor be the same. Table 1 shows the intensification factors determined for four different x-ray emulsions. I is the emulsion used in the preceding experiments, II is another emulsion made by the same manufacturer, and III and IV are the products of two other makers.

TABLE 1.

	60 kv			120 kv		
D	0.4	1.2	2.0	0.4	1.2	2.0
Emulsion I	4.9	8.9	11.0	10.2	13.2	19.5
Emulsion II	5.8	8.9	10.2	7.2	12.0	13.8
Emulsion III	7.6	13.8	13.8	12.9	18.6	19.5
Emulsion IV	2.6	7.2	8.5	4.6	8.6	12.9

Summary. The speed of intensifying screens is found to increase with shortened development time; to increase with increase of tube potential; to be independent of the tube current from 2 to 35 ma; to be independent of the target film distance from 9.5 to 2.5 meters; to increase as more filtering medium is interposed between the tube and screens; and to vary considerably with the photographic emulsion used.

THE PATTERSON SCREEN CO.,
TOWANDA, PA.

AN APPARATUS TO MEASURE COLOR TEMPERATURE OF INCANDESCENT LAMP FILAMENTS

By Clayton H. Sharp

The incandescent lamp has been a reality for 50 years. During all this time it has been known that the temperature of the filament is the most important factor in determining its efficiency and its life, but practical means for the rapid and accurate determination of this temperature have been lacking. Instead, the efficiency of the lamp has been used as a measure of its temperature.

In the earliest days Edison stated efficiency in terms of the number 16 cp lamps per horsepower. Later, with the further development of the electrical units, "watts per candle," which is a kind of inverted efficiency, was used and continued to be used until in relatively recent years the efficiency measurements have been made in lumens per watt. While these terms have considerable value in illuminating engineering yet as far as the lamp itself is concerned they have been used only as figures which give a kind of measure of the operating regime of the lamp, that is, of its filament temperature.

The early measurements of filament temperature were pyrometric measurements and gave figures which represented the temperature of a black body having the same brightness as the filament surface.

In recent years a more convenient measure of the temperature of a lamp filament has been developed in the form of its so-called "color temperature." By color temperature is meant the temperature of a black body at which the integral color of its light matches that of the lamp.

The difference between true temperature and color temperature of tungsten filaments has been investigated and is known. This difference is smaller than is the difference between the true temperature and the brightness temperature of a filament as measured by a pyrometric method.

Color temperature standard lamps, the relationship between volts and the color temperature of which is known, have been developed and are available.

One thing which has stood in the way of considerable application of color temperature measurements is the difficulty of making the req-

uisite color match with satisfactory facility. The ordinary procedure is to put the lamps to be color matched on a photometer bar and to adjust to a condition of no color difference between the fields of the photometer at equal brightness. The Lummer-Brodhun contrast prism photometer seems to be the most sensitive to color differences. By taking the mean of a suitable number of measurements made by various observers a surprisingly high degree of accuracy in terms of color temperature is attainable in this way, but evidently the method is not a very practical one for extensive use and color temperature measurements have been made only in rather special cases.

Dr. N. R. Campbell,[1] at the Research Laboratory of the General Electric Company of England, has devised an ingenious and sensitive method for color matching lamps by the use of photoelectric cells. He uses a sodium and a rubidium cell connected in series with a battery, with an electrometer connected between the conductor joining the cells and a suitable point on the battery. Sodium is sensitive to blue light but has practically no red sensitivity. The sensitivity of rubidium extends more toward the red of the spectrum. The theory is that by suitable adjustments, the current response of the sodium cell can be made the same as that of the rubidium cell with light of a certain color, that is, with the lamp at a certain color temperature. If another lamp is substituted for the first and the same response condition is obtained the color temperature of the second lamp will be the same as that of the first even though the intensity of the light may be very different. In carrying out this idea Campbell mounts his two cells on a rotator so that they describe the same path in the light of the lamp. This procedure is necessary to make sure that no intensity effect enters in. An adjustable diaphragm is placed in front of the more sensitive of the two cells so that the equal response adjustment can be made. This apparatus has been reduced to such form as to make it available for practical use in the rating of lamps.

The present paper presents quite a different form of apparatus whereby color matching can be done with great facility. The same principle is applied as Campbell uses that if two lamps are at a color match, the ratio of the intensity of a light from a given blue region of

[1] Journal of Scientific Instruments, *2*, p. 177; 1925; *4*, p. 38; 1926.

In the discussion following the presentation of this paper at the meeting of the Optical Society of America, October 26, 1929, Dr. Herbert E. Ives referred to an article which he had published in the Electrical World, Volume 59, page 1268, 1912, in which he proposed a procedure for determining the operating regime of an incandescent lamp by balancing, by a nul method, the energy effect of one part of the spectrum against that of another.

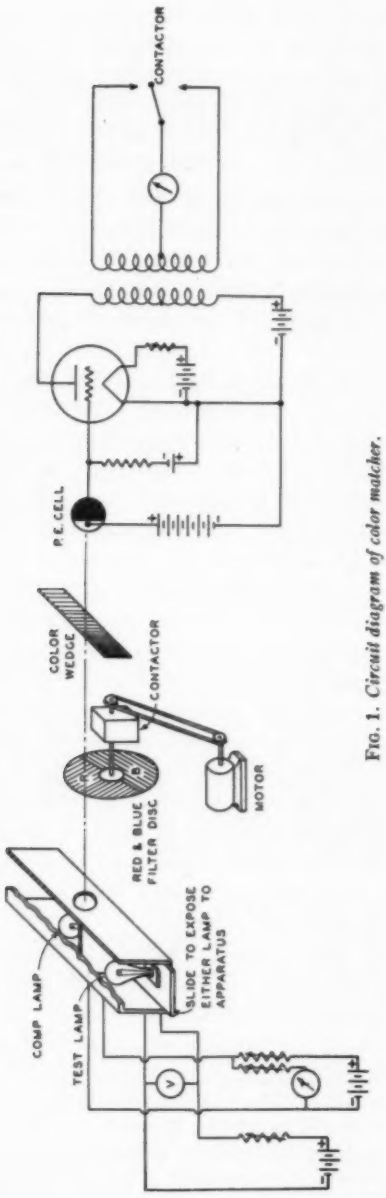

FIG. 1. *Circuit diagram of color matcher.*

the spectrum to that of a given red region defines the spectral distribution and hence, the temperature. Evidently, these regions can be selected arbitrarily if relative values only are required.

Instead, however, of using two photoelectric cells of different response characteristics, a single caesium cell is used which is sensitive over the entire spectrum, and the red and blue selection is made by the use of transparent filters. These take the form of a rotating disc one-half of which is of red celluloid and the other half of blue celluloid. The light from the lamp passes through this disc to the caesium cell. The latter is connected to an amplifier circuit, as shown in the diagram (Fig. 1) in such a way that when the disc is rotating, if the effect of the red filtered light on the photoelectric cell is greater than that of the blue filtered light, the galvanometer deflects in one direction and if the other condition obtains, the deflection is opposite.

A combination of red and blue celluloids with a caesium photoelectric cell is found such that the red and blue will just balance each other at some temperature of the lamp. Evidently, the value of this temperature can be determined by substituting a standardized lamp for the unknown lamp and varying its voltage, until the balance is once more obtained.

Let us suppose that this balance is at a relatively low temperature. In order to deal with lamps of higher temperatures the apparent color temperature of the light is lowered by the introduction of a yellow filter of suitable density and, by substituting the standard lamp, this temperature is determined. As a practical matter a color wedge is used which is moved into the beam until the balance is obtained. By the use of auxiliary fixed filters together with a color wedge any practicable temperature can be measured. Evidently, blue filters could be used for the reverse effect but this, in the cases which have been tried, does not seem to be so good a procedure.

Obviously, given a photoelectric cell with a linear characteristic, the value for the color balance is unaffected by the candlepower of the lamp. Linearity of the amplifier is not required. The diagram shows only one amplifier tube. In practise it has been found desirable to use three tubes with capacitance coupling. The photoelectric cell and the amplifying train are enclosed in a heavy copper box which acts as a shield against extraneous disturbances.

The contactor (Fig. 2) is driven from a cam on the shaft on which the disc is mounted and changes the transformer connections during the time that the light is constant, that is, when the middle portion

of the red or the blue filter is in the beam. At this time no current is flowing in the secondary windings of the transformer.

The comparison lamp shown in the diagram is calibrated by comparison with standardized lamps and for routine work the instrument "*T*" may carry a scale of temperatures. At the outset of work a standard lamp is introduced in the test lamp socket, a match is made with the wedge, the comparison lamp is substituted and its voltage is adjusted until a balance is attained. Then the variable resistance in series with "*T*" is changed until this instrument reads the color temperature of the standard lamp. Since the intensity of the light does not matter,

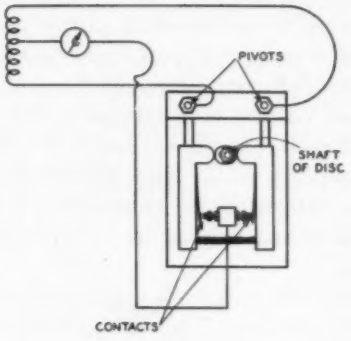

FIG. 2.

the lamp may be put into the apparatus in any position provided that the position is such that the color of the beam reaching the photoelectric cell is the same as the integral color of the entire lamp, taking into account the cooler portions as well as the hotter portions of the filament. No critical adjustments seem to be required to reach this condition.

In lamp testing an apparatus of this kind is conveniently mounted on an integrating sphere so that color temperature measurements can be made simultaneously with photometric measurements. In this case the color of the sphere paint may modify the color from the light of the lamp to an appreciable degree but since the calibration is made with a standard inside the sphere this effect cancels out.

It has been found that an ordinary lamp tester can learn to use the apparatus very quickly and that in working with an integrating sphere the color temperature measurements are made quite as rapidly as

photometric measurements using a photoelectric photometer. The accuracy of such measurements made rapidly on ordinary commercial lamps under these conditions is within perhaps 5°K. By taking more time and working more carefully differences as small as one or two degrees K may be detected with certainty.

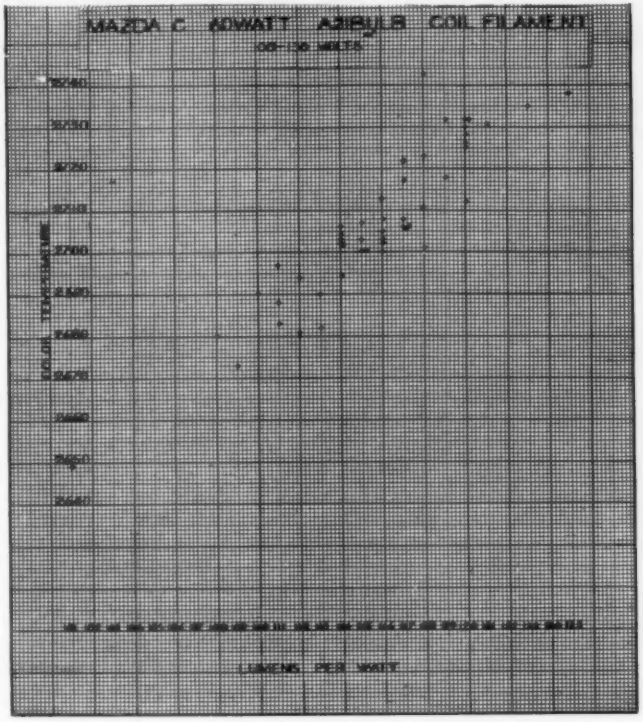

FIG. 3.

The galvanometer used is a small Leeds and Northrup box type instrument which is not only very convenient but is entirely adequate for the purpose. A potentiometer, such as is used in radio work, is put as an Ayrton-Mather shunt on the galvanometer so that the instrument is properly damped and so that the sensitivity can be varied as required.

The availability of this apparatus opens a very interesting field for investigation with respect to incandescent lamps. Consider, for example, Fig. 3 which shows the color temperature and lumens per watt for a

lot of 60 watt lamps. The relationship between lumens per watt and color temperature is very well defined but it will be seen that there are certain individual deviations from the general trend which may be quite significant. For example, at 11.8 lumens per watt there is one lamp at 2710°K and another at 2743°K. If these lamps were to be given a life test they would, under the usual procedure, be operated at the same efficiency. The color temperature measurements show,

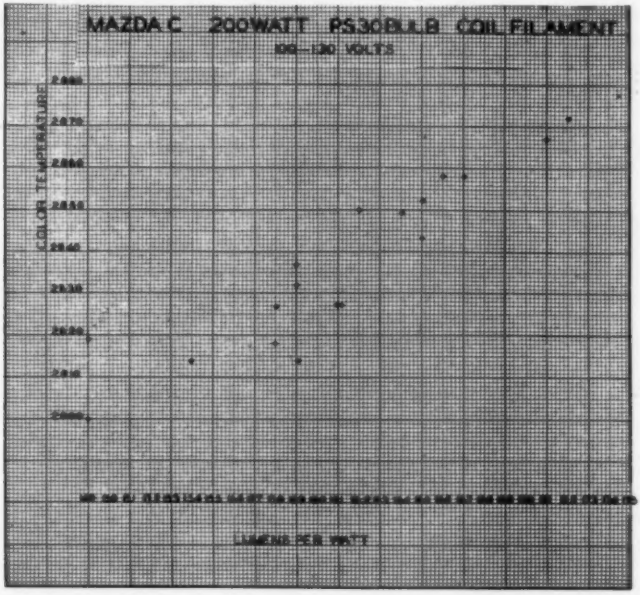

FIG. 4.

however, that they differ in temperature by more than 40 degrees. It is scarcely to be expected that they should yield the same life value. Which is the true criterion for the life of these lamps? Should they be tested at the same color temperature or at the same efficiency? Evidently, the answer to this question can be obtained only through a very considerable series of life testing operations. Fig. 4 shows similar measurements made under commercial conditions on a lot of 200-watt gas-filled lamps.

The relationship between lumens per watt and color temperature has been worked out by Forsythe and by Priest for vacuum lamps. Data

of this kind can be applied only to a given type of lamp construction because lead-in wires and anchor wires change conditions. The conditions for a straight filament are not the same as for a spirally-wound filament. For the spirally-wound filament there is an appreciable blackening of the radiation so that the relationship between color temperature and true temperature is not the same as it is with the straight filament. Obviously, when the filament is surrounded by a gaseous

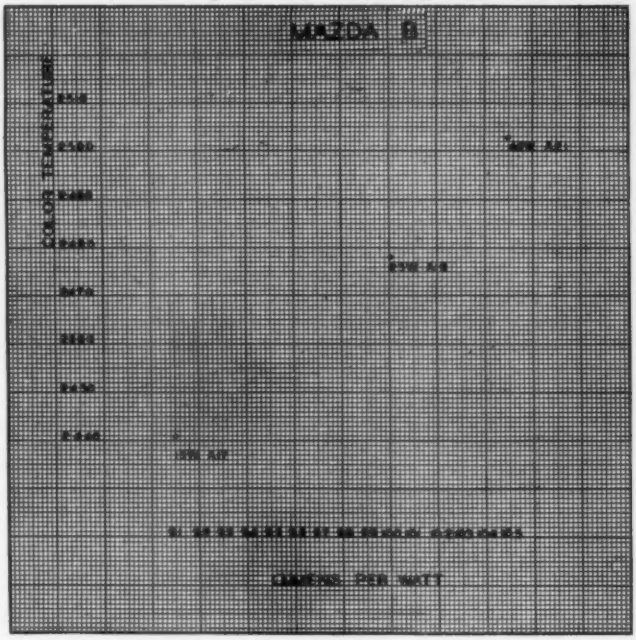

FIG. 5.

atmosphere conditions are profoundly changed and probably the most that can be done is to give the relation between lumens per watt and color temperature for a given standard size and construction of lamp. Reference is made in this connection to Figs. 5 and 6 in which average values of color temperature for lamps of different sizes are plotted against lumens per watt. Lamps are designed to give a uniform life and gasfilled lamps of different types and sizes cannot be expected to fall on a smooth color temperature curve. (Note particularly the 200-watt high volt (H V) lamps.)

With this apparatus it is much simpler to measure color temperature of lamps than it is to measure the efficiency of the same lamps with existing appliances.

In view of the fact that filament temperature is, from an engineering point of view, the most significant datum of our lamp, it is not unreasonable to suggest that color temperature measurements may, in

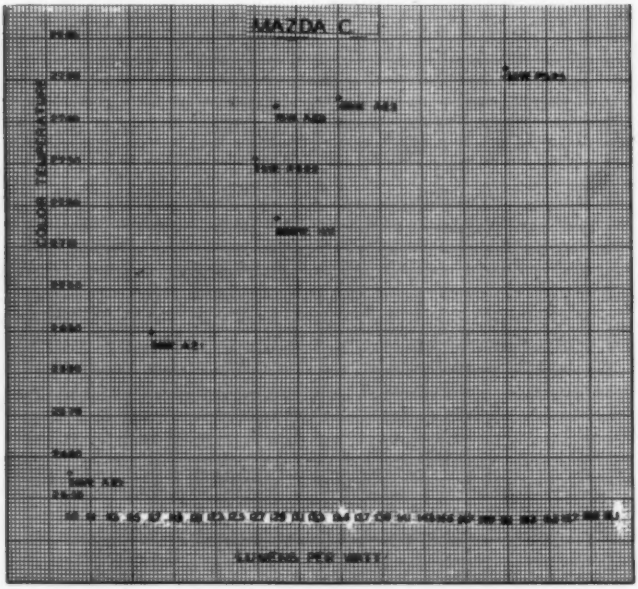

FIG. 6.

many cases, supplant photometric measurements though, of course, photometric data will always be required.

Obviously, this apparatus lends itself to other applications such as to the measurement of furnace temperature and to the automatic recording of the same. It may even prove to offer a quick and convenient means for matching pigments which are of similar make-up and hence of a comparable spectral composition. The matching of the colors of papers and of textiles is another promising field of application.

ELECTRICAL TESTING LABORATORIES,
NEW YORK, N. Y.

PHOTO-CONDUCTIVITY IN DIELECTRIC LIQUIDS

By Willard H. Eller

A number of investigators have shown that the conductivity of dielectric liquids is increased when exposed to light. This work was undertaken with a view to the possible relation which this phenomenon might have to the characteristic "end absorption" exhibited by most organic liquids.

Bequerel[1] has shown that solid paraffin increases in conductivity when exposed to beta and gamma rays. J. J. Thomson,[2] P. Curie,[3] Jaffé[4] and Hodgson[5] have shown an increase in conductivity of certain liquids when exposed to x-rays, and gamma rays from radium.

Stark and Steubing[6] have observed photoelectric phenomena in poorly conducting organic liquids.

Cunningham[7] investigated the effect of ultraviolet light and x-rays upon solutions, but did not obtain satisfactory results.

Jaffé[8] has obtained ionization in hexane, using radium to produce the ionization, and has found the mobilities of the positive and negative ions to be 6.03×10^{-4} and 4.17×10^{-4} cm/sec/volt/cm, respectively. The recombination of these ions in hexane appears in agreement with the formula $dn/dt=-\alpha n^{1.84}$ instead of the theoretical value of $dn/dt=-\alpha n^2$.

The only previous work in which ultraviolet light has been used exclusively to produce ionization in organic liquids of the type being used by the author is that of Szwessy and Schäfer,[9] Naccari,[10] and Timpanaro.[11] Szwessy and Schäfer subjected paraffin oil to ultraviolet radiations with the following results: (1) the electrical conductivity is increased; (2) the strength of the ionization current is, at low potential

[1] Bequerel, Comtes Rendus, *136*, p. 1173; 1903.
[2] J. J. Thomson, Nature, *55*, p. 606; 1897.
[3] P. Curie, Comptes Rendus, *134*, p. 420; 1902.
[4] G. Jaffé, Jour. de Phys., (4), *5*, p. 263; 1906. Ann. d. Physik, (*25*), *2*, p. 257; 1908.
[5] Hodgson, Phil. Mag., *18*, p. 152; 1909.
[6] Stark and Steubing, Phys. ZS., *9*, p. 481; 1908.
[7] Cunningham, Proc. Camb. Phil. Soc., *11*, p. 431; 1902.
[8] G. Jaffé, Ann. d. Physik, (32), *1*, p. 148; 1910.
[9] Szwessy and Schäffer, Ann. d. Physik, (35), *3*, p. 511; 1911.
[10] Naccari, N. Cimento, (6), *2*, p. 233; 1912.
[11] Timpanaro, N. Cimento, *24*, p. 203; 1922.

gradients, proportional to them, but increases slower than the potential, reaching a limiting saturation value; (3) the ionization current produced increases with the duration of the radiation, reaching a final definite maximum value; (4) the current strength is independent of direction; (5) the ionization produced by ultraviolet shows quite similar behavior to that produced by gamma rays. Timpanaro also showed increased conductivity in paraffin oil due to ultraviolet radiation. Naccari found that the conductivity of toluene was increased by the action of sunlight.

Szwessy and Schäfer indicated an upper limit for the wave length of the radiations to ionize paraffin oil by placing mica, of 0.2 mm thickness between their ionization cell and the source of radiations, no change in conductivity resulting. They do not state the wave length at which the screen cuts off, but according to measurements made on mica by the author, this would be in the neighborhood of 3300A.

APPARATUS

A quartz-mercury arc was used as a source of light, the radiations from which were allowed to fall upon the liquid in the absorption cell shown in plan in Fig. 1 (a). *AA* are the side walls of the cell, and *C* the

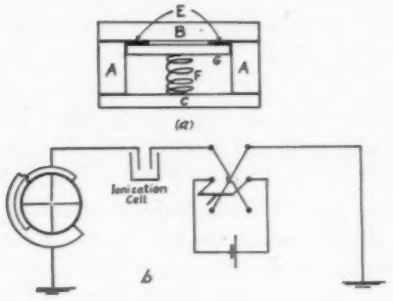

FIG. 1. *Absorption cell and diagram of connections.*

back of glass. *B* is a quartz plate, *E*, platinum electrodes held against *B* by the glass plate *G* and the spring *F*. The entire cell was held together by a clamp of insulating material, not shown in the drawing.

The liquid was placed in the main body of the cell between *G* and *C* and a thin layer, 0.085 mm thick, and 1 cm between the electrodes was held by capillarity in the space between *B* and *G*. It was this thin layer of liquid which was exposed to the action of the ultraviolet light, the

beam being sent through a diaphragm so that no light fell on the electrodes.

The cell was connected in series with a battery and electrometer as shown in Fig. 1 (b), with a reversing switch to obtain flow in either direction. The light was admitted to the cell through a tube containing diaphragms and a suitable shutter to cut off the light when desired. Arrangement was also made at the end of the tube nearest the light for interposing screens to cut off certain regions of the radiations.

After obtaining the ionization data for the various liquids when exposed directly to the mercury arc as just described, a simple quartz prism monochromatic illuminator was substituted in place of the tube containing the diaphragms. The monochromatic illuminator was used in such a manner that the liquid could be exposed to a band of wavelengths about 200 Angstroms in width, the most of the intensity of the radiation being of course confined to the mercury lines included in the band.

RESULTS AND DISCUSSION

The work here described was all done in the region of the ultraviolet from about 2300 Angstroms up. The following liquids, all of the paraffin group of simple hydrocarbons were studied; paraffin oil (commercial), n-tetradecane ($C_{14}H_{30}$, di-isoamyl decane ($C_{10}H_{22}$), n-decane ($C_{10}H_{22}$), n-octane (C_8H_{18}), and iso-octane (2–2–4 tri-methyl pentane). The n-tetra decane, di-isoamyl decane and n-octane were of the best obtainable from the organic supply houses, while the n-decane and iso-octane were specially purified materials.

The general effects of the ultraviolet light were the same for all the materials used, and were in agreement with the results obtained by Szwessy and Schäfer on paraffin oil.

In addition, however, we have shown that there exist definite threshold values of wave length to produce ionization, and that within the limits possible in the measurements made, these correspond with the absorption limits of the liquids. These liquids all exhibit the end absorption, thus differing from such substances as benzene, which has absorption bands in the ultraviolet showing a vibration structure. It was impossible to obtain any change of conductivity in benzene.

It was first shown, before using the monochromatic illuminator, that the region of ionization for all the liquids was entirely in the ultraviolet, by interposing a mica screen between the mercury arc and the ionization cell. This screen was of clear mica, 0.035 mm in thickness, cutting off all radiation below 2900A. There was no change in the

conductivity of any of the liquids with the screen in place, thus showing that light of wave length greater than 2900A had no effect, and that there also was no change in conductivity due to the heating effect from these radiations.

After the maximum ionization was reached, upon direct exposure of the liquid to the arc, the light was cut off and readings taken to obtain the increase in resistance as recombination took place. This is shown in the curves of Fig. 2. In these curves, as in all the others, the

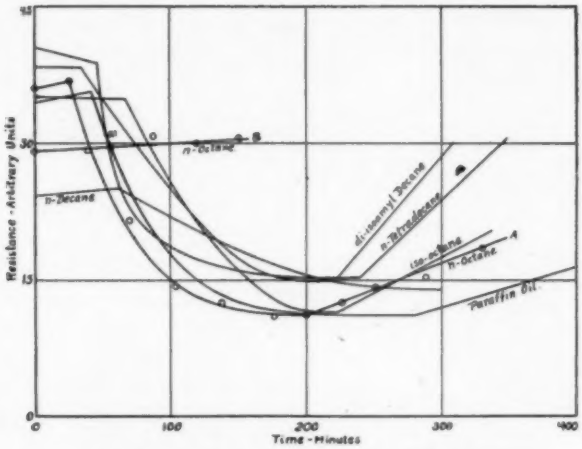

FIG. 2. *Effects of illumination upon liquid resistance.*

ordinates represent the resistance of the liquid, plotted on an arbitrary scale. The abscissas are time in minutes. The straight lines of the recombination curves would indicate that recombination takes place in accordance with the theoretical formula $dn/dt = -an^2$. We may show this as follows: Let r and t represent the resistance and time, respectively, then the equation of the curve is $t = a'r + b$. But r is proportional to $1/n$, where n is the number of ions present. Then $t = a'/n + b$ and so $dn/dt = -an^2$.

Paraffin oil showed the greatest ionization of any of the liquids. This is not, of course, a single compound. The ionization of paraffin oil is shown in Fig. 2 for direct exposure to the light source. This curve needs little explanation as it is apparent how the ionization increases rapidly at the beginning, finally reaching a maximum constant value, and recombination beginning at once when the light is cut off.

That a threshold value of wave length to produce ionization exists is evident from the curves of Fig. 3, where the monochromatic illuminator was used. Curve A shows no ionization, in fact, shows a slight increase in resistance during the time of exposure, of about the magnitude that would sometimes occur when taking readings without the light. The shortest wave length in the band in this case was 2900A, the same, in fact, as that at which the mica screen cut off. Curve B is for exposure to the band from 2750A to 3000A and shows marked ioniza-

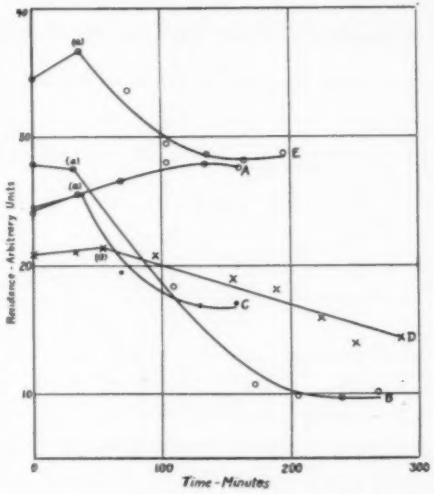

FIG. 3. *Curves indicating threshold wave length to produce ionization.*

tion. The strongest mercury lines here included are 2894A, 2857A, and 2804A. From the absorption spectra, Fig. 7, we see that the absorption limit for paraffin oil is 2870A, so, since the threshold wave length for producing ionization must lie between 2750A and 2900A, it is evidently one of the strong lines of the band, and probably either the one at 2804A or 2857A. The lines in the band below the threshold value will also assist in causing ionization, hence we cannot say definitely which is the longest wave length that is effective. However, the threshold value is very near to, and in all probability coincides with, the absorption limit.

n-Tetradecane, while ionizing very readily when exposed to the full arc, is not affected as much as paraffin oil, Fig. 2. The recombination curve is a straight line, as previously stated when dealing with all of the curves.

Fig. 4, curve A, shows that no ionization occurs in n-tetradecane with the mica screen interposed between the liquid and the arc. This curve is included to show the lack of effect, and is characteristic of the results found in every case where the mica screen was used. It may be noted that at point (d), where the screen was removed, the conductivity increased rapidly. The portions of the curve ab and bc are for mica screens thicker than that discussed above. Curve B, between points (a) and (b) is for exposure to the band between 2900A and 3100A which had no effect, while from (b) to (c) the band including 2750A to 3000A was used, this containing the strong lines of 2857A and 2894A, with

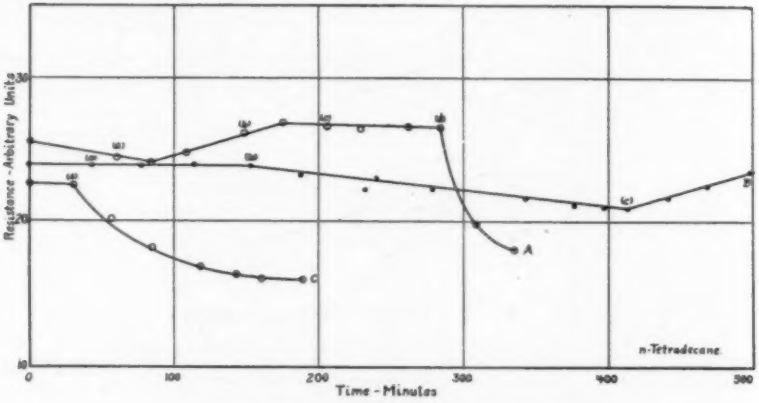

FIG. 4. *Resistance curves of n-tetradecane.*

the one of maximum intensity at 2804A. The latter is very close to the absorption limit of 2810A. Curve C is for exposure to the same band as the second part of B, and is included due to the fact that the effect is rather small. No other band of wave lengths was used in the case of n-tetradecane due to the lack of both time and material.

The decrease of resistance of di-isoamyl decane, upon direct exposure to the arc, is shown in Fig. 2. It may be noted that the curve does not drop off so abruptly as for the preceding substances, though there is a large change in the resistance.

Fig. 5, curve A, shows no effect for the band 2750A to 3000A, but there is a large change in the resistance due to the band 2500A to 2800A (curve B). This contains the strong line at 2699A and the triplet at 2655A, 2654A, and 2652A. There is still ionization, but not so strong,

by the band 2450A, to 2650A, (curve C), this containing the strong 2536 A mercury line.

Undoubtedly the quite intense ionization shown by curve B is due mainly to the strong triplet included in the band, but the presence in this band of the strong line at 2699A and its absence (or at least its low intensity) in the preceeding one shows close agreement between the ionization threshold and the absorption limit at 2700A.

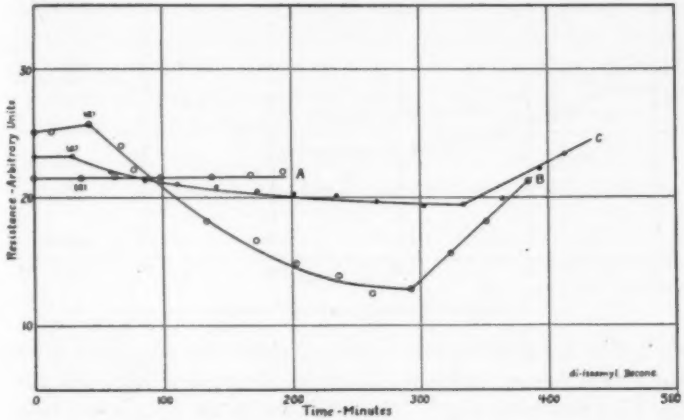

FIG. 5. *Resistance curves of di-isoamyl decane.*

n-Decane does not show nearly the amount of ionization that the iso-decane does, either upon direct exposure to the arc, or when using the monochromatic illuminator. The less steep ionization curve found for iso-decane is again evident here, however. It was impossible to obtain a satisfactory recombination curve with this liquid. Some recombination data obtained when using the monochromatic illuminator indicate, however, the usual straight line type.

Here, as in the case of iso-decane, the band 2750 A to 3000A failed to have any effect (Fig. 6, curve A, part bc), the first sign of ionization being in the region between 2500A and 2800A, containing the strong line 2699A and the strong triplet 2655A, 2654A and 2652A. The absorption spectrum shows a limit slightly lower than for iso-decane, at about 2660A, very near the strong mercury triplet, thus again showing the agreement between photo electric threshold and absorption limit.

Both forms of octane showed a quite large effect on direct exposure to the arc, Fig. 2, but neither could be made to give a threshold value. This does not indicate that such a value does not exist, but is probably

due to the lack of intensity obtained with the monochromatic illuminator in the region where it should occur. The absorption pictures show the same limit for both forms at 2365A. The band obtained with the monochromatic illuminator immediately above this value, from 2450A to 2650A, was fairly intense and showed no effect whatever. This is

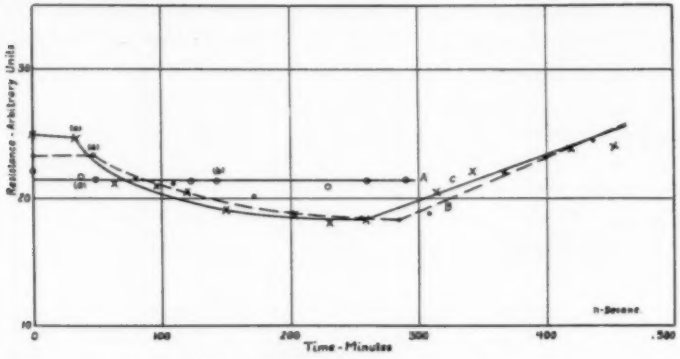

FIG. 6. *Resistance curves of n-decane.*

shown in Fig. 2, curve B, for n-octane. Neither was any effect shown in the next band below, which included the absorption limit, but the intensity here was very weak. The results with the octane are then inconclusive insofar as establishing a threshold is concerned but, judging by the results obtained with the other liquids, it must exist.

The recombination curves are of the same form as with the other substances. They, as well as paraffin oil, show a much slower rate of recombination than do n-decane and n-tetradecane.

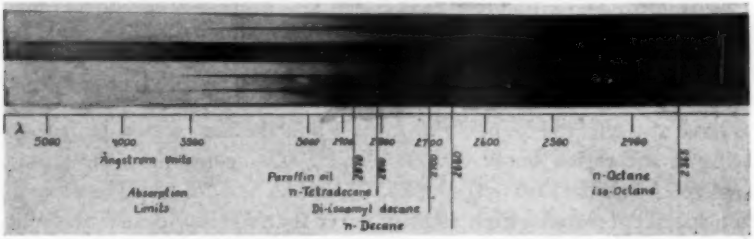

FIG. 7. *Absorption spectra of liquids studied.*

Fig. 7 shows the absorption spectra for the six liquids. The limits are not sharply defined in the print. The measurements for these limits were taken from the original plates and are indicated on the figure.

Outside of the inconclusive results obtained with the octanes it would seem that the normal compounds are more difficult to ionize than the isomers in the paraffin series of hydrocarbons. This is shown best in the case of n-decane and iso-decane, where the latter shows a much greater change in resistance due to the action of the light both when exposed directly and when using the monochromatic illuminator. We may also make some comparison in the case of n-tetradecane and paraffin oil, though due to the indeterminate character of the latter we can consider it only as an indication, rather than as direct evidence. However, these both have nearly the same absorption limit, so the paraffin oil must consist almost entirely of the higher liquid members of the group, and undoubtedly contains some isomers.

The following table shows a summary of the absorption limits and the strongest mercury lines in the bands which first produce ionization.

Substance	Absorption limit	Nearest lower strong Hg line in band where ionization begins
Paraffin Oil	2870 A	2857 A
n-Tetradecane	2810	2804
Di-isoamyldecane	2700	2699, (2655, 2654, 2652)
n-Decane	2660	2655, 2654, 2652
n-Octane	2365	——
iso-Octane	2365	——

CONCLUSIONS

1. From the results here obtained we may state that the ionization produced by ultraviolet light in the dielectric liquids tested has a threshold value which corresponds very nearly, if not exactly, with the absorption limit.

2. The absorption limit, as well as the threshold ionization wave length, increases as we go toward the higher members of the paraffin group.

3. The form of the recombination curves would indicate that the theoretical law of recombination, namely, $dn/dt = -an^2$ is obeyed by these liquids when ionization is produced by ultraviolet light.

4. Due to the slowness with which recombination takes place the mobilities of the ions formed must be very small, thus indicating heavy ions such as would result from breaking up the molecule. This might throw interesting light upon the toxic effects of violet and ultraviolet light on living organisms.

5. Though somewhat inconclusive it would seem that the normal compounds of the paraffin series are more difficult to ionize than the isomers.

This work was done at the University of California and the author wishes to express his thanks to the members of the Department of Physics, particularly to Professor Brackett for his help and guidance in the course of the work.

PHYSICS LABORATORY,
UNIVERSITY OF HAWAII,
OCTOBER 8, 1929.

INFRA-RED TRANSMISSION OF THE FLESH

By C. Hawley Cartwright

ABSTRACT

The spectral energy of a light transmitted through the cheek was tested photographically in the region of $\lambda 0.86\mu$, and also by a spectrometer throughout the whole spectrum. A very sensitive vacuum thermocouple was used. The photographs of the spectrum showed 14% transmission of $\lambda 0.86\mu$ through the cheek. The cheek transmitted a maximum of 20% at $\lambda 1.15\mu$ and the water in the body cut off the longer wave lengths. The spectral energy transmitted by bacon fat was found to be similar to that of the cheek; however, it transmitted nearly five times as much energy. The ordinary incandescent electric light with filters to cut out the visible and infrared beyond $\lambda 1.4\mu$ is ideal for deep penetration of light into the body.

The fact that physicians were uncertain which type of therapeutic lamp among the many in use was most beneficial suggested the problem of finding which wave lengths penetrated the body, with their various intensities. Dr. Carl Sonne[1] of the Finsen Light Institute of Copenhagen, Denmark, has done very creditable work in this field both in a therapeutic and physical way. This work supplements the work of Dr. Sonne, and gives more physical quantitative data.

The cheek was chosen as a medium of transmission as it seemed representative of the body as a whole.

A spectrum of the light transmitted through the cheek was obtained by means of a very fast spectrograph (f 2.7) with a glass prism and Zeiss quartz-florite lenses 6 cm in diameter. A piece of opal glass 2 mm thick was placed in front of the spectrograph slit in order to completely diffuse the light emitted from a 15 watt electric light bulb situated 5 mm in front of the opal glass. The bulb was placed in the mouth so that a portion of the cheek 5 mm in thickness intercepted the light passing through the spectrograph.

The upper photograph in Fig. 1 was taken with three seconds of exposure before the cheek was interposed. The intensities of the various regions are characteristic of the infrared plates employed here. The second photograph was taken with 21 seconds exposure to the light transmitted through the cheek. From a large number of photographs, it was found that the cheek transmitted approximately 14% in the region of $\lambda 0.86\mu$. However, the entire spectral distribution was obtained by replacing the photographic plate by a special vacuum thermo-

[1] Archives of Physical Therapy, X-ray & Radium, *10*, No. 3.

couple mounted on a micrometer screw in such a way that it could be moved across the spectrum. This thermocouple, built by the author, possessed a sensitivity of 1 microvolt for 1×10^{-8} cal/sec falling on a narrow receiver of 1 mm² area. The instrument was so steady that it was possible to traverse the entire spectrum without the zero shifting to any appreciable extent. It reached thermal equilibrium in approximately one second.

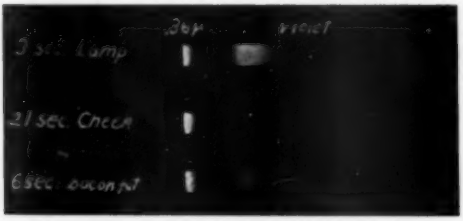

FIG. 1. *Transmission of light through the cheek and bacon fat 5 mm thick for λ.86μ.*

The mouth was held open over a mirror in order that a condensed beam of light from a 500 watt bulb might be reflected so as to pass through the cheek to the slit of the spectrometer. The slit was quite wide so as to obtain sufficient energy in the spectrum.

Curve A in Fig. 2 shows the intensity distribution of the source of light and curve B the intensity distribution as transmitted through the cheek. The resolving power was low because the thermocouple covered a spectral range of λ0.06μ at λ0.9μ.

Fig. 3 shows the percentage transmission as calculated from several curves as in Fig. 2. The cut-off for long wave lengths is undoubtedly due to the water in the cheek.[2]

Dr. Sonne[3] investigated the light reflected by the cheek and found it to be about 34% in the entire region here investigated. The calculations for the absorption coefficient should take this in account.

It may be assumed that the power of light to penetrate the body depends on both the individual and on the particular portion of the body under treatment. This being the case, it was decided to discover what light would penetrate fat; the amount of which probably constitutes the greatest point of difference between individuals subjected to treatment by light.

[2] Edison Pettit, Astrophysical Journal, *66*, 1927.

[3] Dr. Sonne, Archives of Physical Therapy, X-ray & Radium, March 1929.

With the help of Dr. Caroline Bedell, the transmission of bacon fat was investigated. The lowest photograph of Fig. 1 shows the trans-

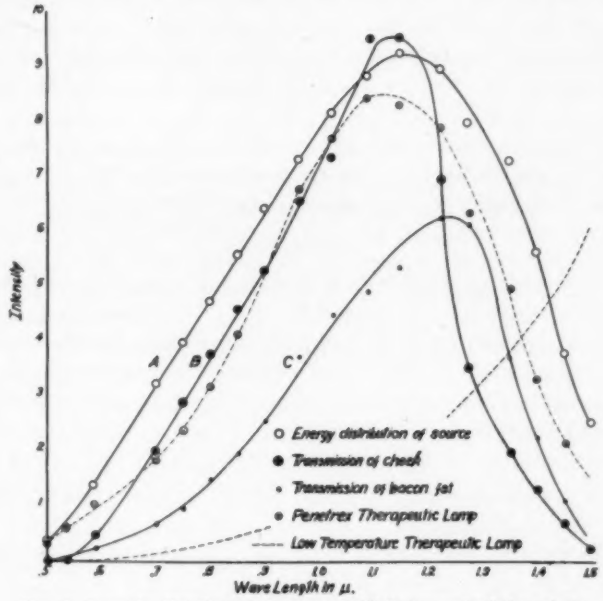

FIG. 2. *Intensity distribution of source and light transmitted through the cheek and bacon fat each 5 mm thick.*

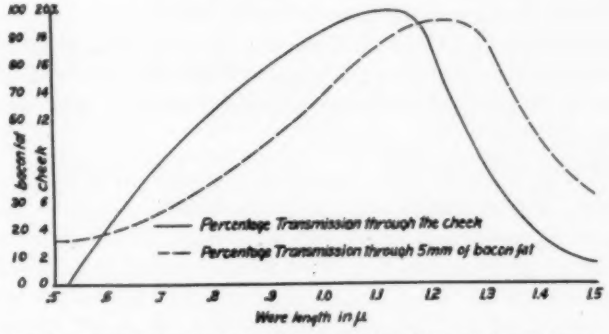

FIG. 3. *Percentage transmission of infra-red through the cheek and through bacon fat each 5 mm thick.*

mission of a piece of bacon fat 5 mm thick taken with 6 sec. exposure. Curve C in Fig. 2 shows the intensity distribution of light through a

piece of bacon fat 5.0 mm thick. Fig. 3 shows a percentage transmission curve for bacon fat 5 mm thick obtained from photographs and the curve C in Fig. 2. The spectral distribution of light by bacon fat is very similar to that of the cheek; however, the bacon is nearly five times more easily penetrated. Hesselbalch found that the transmission in the ultraviolet of living and dead skin showed no measurable differences.[4]

Two curves are plotted in Fig. 2 showing the intensity distribution of two types of therapeutic lamps, a low temperature infrared generator and the Penetrex a high temperature lamp.

CONCLUSION

Flesh is most penetrable to a radiation of about $\lambda 1.15\mu$; the water cuts off wave lengths longer than $\lambda 1.4\mu$. A therapeutic lamp for radiation to penetrate most deeply into the body, therefore, should be one equipped with filters which exclude the spectral region except between $\lambda 0.7\mu$ and $\lambda 1.4\mu$ for the reason that more intense radiation of these wave lengths can be concentrated on the body without overheating the skin. Such a lamp is the ordinary incandescent light, since its maximum energy is in this region. It is desirable to filter out visible radiation because it is ineffective for penetrating the body and is moreover very irritating to the eyes. This can be accomplished by using a thin water cell with walls of a filter or a dye in the water.

The very low absorption of bacon fat and the fact that 20% of light of $\lambda 1.15\mu$ can penetrate through 5 mm thickness of flesh makes possible the use of a therapeutic lamp for internal heating.

I am indebted to Mr. R. S. Danforth for suggesting the experiment and foreseeing the value of the results. I am also indebted to Dr. R. C. Burt for his suggestions and continued interest in this experiment.

CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CALIFORNIA.

[4] Henry Laurens, Physiological Reviews, *8*, No. 1, 1928.

Geometrische Optik. By A. König, Jena. Vol. 20, Part 2 of the Handbuch der Experimentalphysik edited by W. Wien and F. Harms. xii+570 pages with 258 illustrations. Akademische Verlagsgesellshaft M. B. H., Leipzig, 1929.

In accordance with the plan expressed in the foreword of the first volume of this series the author has dealt more in detail with the experimental phase of his subject rather than with the theoretical. It is, however, impossible to treat geometrical optics comprehensively without discussing in some detail the equations dealing with image formation and ray tracing, both algebraic and trigonometric, the aberations and the effect of the placing of the pupil points on the character of the image. The first seven chapters, approximately one fourth of the book, are devoted to this portion of the subject. The eighth chapter gives the departures from the imagery of geometrical optics, as defined in the narrower sense, which arise because of the physical nature of light with its accompanying diffraction effects. In the next chapter the eye is considered as constituting a part of the optical system with which it is used and its influence on the requirements and performance of the complete optical system are considered.

A chapter dealing with the theory of mirrors and prisms is followed by a series of chapters dealing with the different optical instruments. The photographic objective, searchlight, makroprojection apparatus (stereopticon, opaque projector and motion picture machine), spectacle lens, magnifying lens and microscope, microprojection and microphotography are dealt with in turn. The last three chapters are devoted to the testing of optical instruments, the measurement of the index of refraction and photometric methods. The teacher of physics in the college or university will be particularly interested in the portion of the thirteenth chapter dealing with the methods of projection of optical experiments for demonstration to classes.

The book closes with a list of books dealing with geometrical optics, an index of the subjects treated and an index of the authors to whom references are made in the footnotes in the body of the book. The listing of approximately 1,600 names in this author index indicates the completeness with which the body of literature dealing with geometrical optics has been scrutinized in the preparation of this work and, on glancing at the dates in the footnotes, one finds that many articles are included which did not appear before the beginning of 1929. This book constitutes an excellent reference work covering a wide range of material with apparently no important omissions and with the emphasis well apportioned to the the different parts of the subject.

I. C. GARDNER

Die Enstehung des Glaswerks von Schott & Gen: Ernst Abbe, Gesammelte Abhandlungen, Unveröffentlichte Schriften. Fourth volume, first half. XIV+146 pages. Gustav Fischer, Jena.

This is a series of letters by Ernst Abbe and his associates describing in graphic manner the early development of the optical glass plant at Jena. During the past few years the publication of narratives of the important influence which the application of scientific reasearch has had upon different industries has been not uncommon. This collection of letters presents a similar story of the creation of the optical glass industry in the eighties through the scientific work of Abbe and Schott. But this volume differentiates itself from other similar accounts in that the story is told by letters written by the principal participants in the development at the time that it was in progress. They were written and submitted to the Prussian government in furtherance of the request for a grant from the state to permit the researches to be continued and to be inaugurated on a production basis at a time when the demands for money seemed greater than could be met from the private funds of those interested in the work. These letters are especially interesting because of the purpose which dictated the choice of material and method of exposition. Not only does one find a comprehensive description of the prior state of the manufacture of optical glass and an account of the very large amount of research which had been completed before state aid was asked but one also finds the hopes for the future of the optical glass industry which these pioneers held and which must be made sufficiently attractive to appeal to the government. But, although there must have been a temptation to paint the future in a too optimistic vein, it is remarkable that, in nearly all instances, the future predicted has been abundantly realized. Later letters give the contract entered into by Schott, Abbe and Zeiss together with detailed statements of the cost of the new factory to be built and the results to be expected. As a result of this correspondence the government made two grants of money on two successive years totaling 60,000 marks. The volume ends with a report on the glass plant in 1886 by Czapski and an extract from a lecture given in 1896 detailing additional advances in the art of optical glass manufacture.

It is through the agency of Dr. v. Rohr that these letters were found in the files of the government at Berlin and published. The editing and the precision with which the original format and relevant references are presented to the reader is admirable. Those interested in the history of the optical industry are under great obligation to Dr. v. Rohr for this and for his numerous other contributions to this subject.

I. C. GARDNER